Efficient Frequency Conversion at Low-Powers in a Silicon Microresonator Using Carrier Extraction

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Abstract: We demonstrate four-wave mixing in a silicon microresonator at low powers using a PIN diode to extract the generated carriers. We achieve conversion efficiencies as high as -6.6 dB with 7 mW of input power.

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On-chip optical parametric oscillators (OPO) based on four-wave mixing (FWM) represent a solution for light sources in a WDM optical network on a microelectronic chip [1]. Silicon is an ideal material for a low-power OPO and due to its high third order nonlinearity and high confinement for dispersion engineering [2]. While on-chip OPO's have been demonstrated in other material systems such as silica glass [3], silicon nitride [1], and high-index silica glass [4], due to the high nonlinear losses in silicon, a silicon OPO has yet to be realized. The nonlinear losses in silicon are due to two-photon absorption and free-carrier absorption. While two-photon absorption cannot be prevented, previous work has shown that extracting the free carriers in a straight waveguide can enhance FWM conversion efficiencies by as much as 10 dB when pumped with 19 dBm (80 mW) [5].

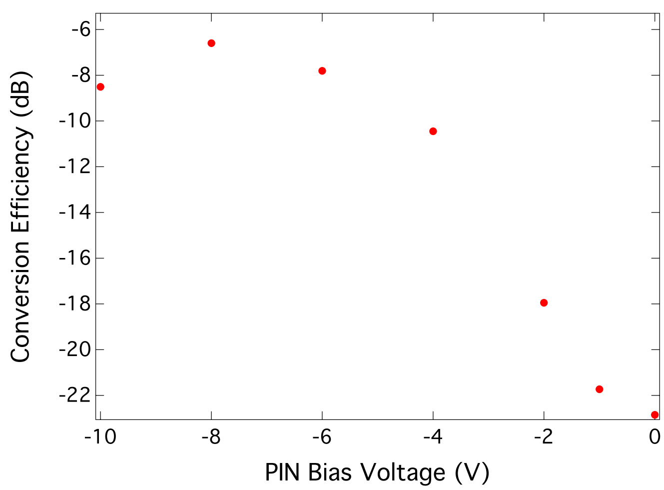

Fig. 1. Conversion efficiency as a function of voltage applied to the PIN diode. The negative sign indicates that the diode is in reverse bias.

Here, we present a silicon microring resonator device with an integrated PIN diode for carrier extraction and show a conversion efficiency enhancement of 10 dB with only 8.5 dBm (7.1 mW) of pump power. At such low pump powers, we obtain a conversion efficiency as high as -6.6 dB. To our knowledge, this is the highest FWM conversion efficiency reported in a silicon microring. The device consists of a 10-µm-radius silicon ring resonator coupled to a bus waveguide. The waveguide is 247 nm high by 550 nm wide and has a slab of 25 nm to allow for carrier extraction. The dimensions of the waveguide, including the slab thickness, were designed to achieve anomalous dispersion within the C-band. The area inside the ring resonator is doped with Phosphorus (N type dopant) while the area around the outside of the ring is doped with Boron (P type dopant) to form a PIN diode. We use the PIN diode to extract the carriers generated due to two-photon absorption and enhance the conversion efficiency of the device by reducing the free-carrier lifetime.

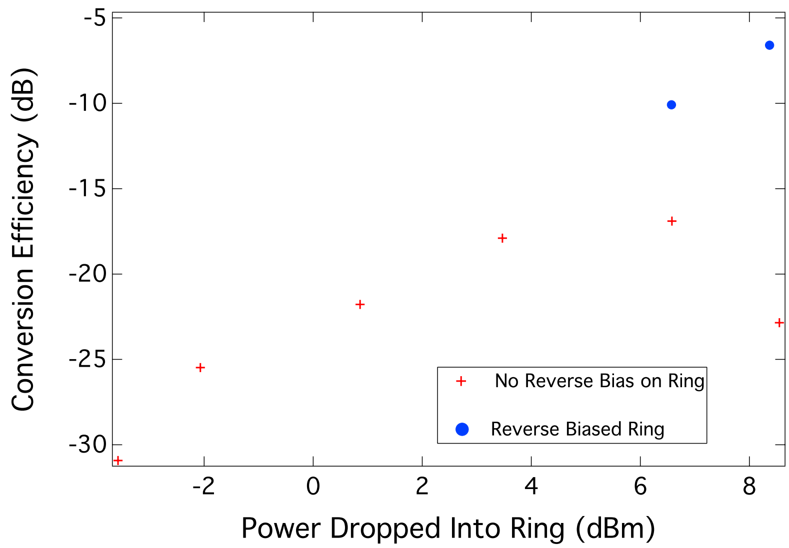

Fig. 2. Conversion efficiency as a function of power in the ring resonator. Approximately 98% of the power in the waveguide is coupled into the ring. The conversion efficiency is measured from the signal and idler powers at the output of the device.

We show a conversion efficiency enhancement of 10 dB by reverse biasing the diode with 8 V. As shown in Fig. 2, when the PIN diode is not biased, free carrier absorption limits the conversion efficiency, which reaches a maximum of -16.9 dB for a power in the ring of 6.6 dBm (4.57 mW). As we increase the power further to 8.6 dBm (7.24 mW) the efficiency drops down to only -22.9 dB. When we reverse bias the diode, we observe a significant enhancement in the conversion efficiency. The conversion efficiency increases from -22.9 dB to -6.6 dB for about 8.4 dBm (6.9 mW) of power. From these results, we calculate that 0 dB conversion efficiency can be achieved with only 11.7 dBm (15 mW) of power in the ring.

In summary, we have achieved efficient wavelength conversion in a silicon microresonator by using carrier extraction to reduce the free-carrier lifetime. By pumping at higher powers, we believe that optical parametric oscillation will be achievable, which will allow for pure silicon-based WDM sources on-chip and for the creation of frequency combs for frequency metrology applications.

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